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CHANGES IN SOIL SPECTRAL REFLECTANCE BY VEGETATIVE COVER

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ABSTRACT

The reflectance characteristics in the 400-1100 nm region of two different soil types and the effect of varying vegetative cover on each are described. The spectral reflectance of the test sites was proportional to vegetative cover and highly dependent on soil color. A vegetative cover of 24-35% was required to significantly effect the spectral reflection (400-1100 nm) of the background soil types. Equations for these relations are given.

INTRODUCTION

Remote sensing of vegetation and soil, whether by electronic or photographic means, is concerned with detecting and representing a number of complex variables. When a target or area within a field-of-view is composed of more than one discrete material, the resulting spectral reflectance from the target will be an average of the spectral characteristics of the components. Thus, when trying to use spectral reflectance to evaluate a target, these variables must be taken into account.

Analysis of color infrared and panchromatic photography and Landsat imagery over arid shrublands and grasslands indicates an absence or extreme sparcity of vegetation. However, when ground checked, a significant vegetative cover can be quite obvious. Detecting and identifying vegetation on these types of imagery is difficult in arid regions because of the small percentage of cover compared to the soil surface area and the highly reflective nature of many arid soils. The significance of the spectral return reaching the sensor requires an assessment of percentage of bare soil, percentage vegetative cover, shadow caused by the vegetation, and how these components affect the target's overall reflectance. Previous work in reflectance characteristics of plants and soil is well known. Condit (1970) showed that conditions affecting soil reflectance include soil texture, color, and soil moisture. Vegetation poses even more of a problem due to extensive three-dimensional and temporal variations. The differences in height, leaf angle, leaf type, crown shape, and color, as well as seasonal differences, all affect the reflectance. The importance of plant color differences was demonstrated using variegated leaves in which the green portion was found to have high reflectance in the infrared and low in the visible region, whereas the white portion of the same leaf was highly reflective throughout the visible and infrared (Knippling,

1970). The differences in spectral response between green and chlorotic vegetation was used by Gausman (1975) to monitor grain sorghum from Landsat I imagery.

The study of the interaction between soil and vegetation reflectance from a forested area showed that those areas with a grass-covered soil had higher near infrared reflectance than a forest of similar type on a bare rock rubble, but in the red region the opposite was true. Soil color/vegetation effects were demonstrated by Colwell (1974) by showing that the total reflectance on a light-toned soil with a grass canopy was higher than that of a dark-toned soil with the same grass cover.

The purpose of this study was to conduct a simple experiment to evaluate the effect on soil reflectance, 400 to 1100 nm, by vegetation, and determine the percent cover needed to alter the background reflectance sufficient to detect the vegetation.

METHODS AND MATERIALS

Two 1.9 m square test plots were constructed, one was filled with light colored, clean, gravelly medium sand (Munsell color 2.5Y9/2), and the other with a commercially available dark, organic loam potting soil (Munsell color 7.5YR2/0, moist). Weight loss on ignition of the oven dry organic soil was 49.6%. The plant species used in this study were marigold (Tagetes sp.) and silver lace dusty miller (Cineraria sp.), that were green (Munsell color 7.5GY4/4) and gray (Munsell color 10GY8/1), respectively. Plants, 10 cm tall, were planted in plastic pots, 16.5 cm diameter x 15 cm tall, and cultured for 30 days. All flower buds were removed from the plants during the study. At the start of the experiment the diameter of the plant canopy was approximately that of the pot diameter, although irregularities in the plant canopy caused it to vary somewhat from the pot diameter. Prior to each data collection, pots containing the marigolds were placed in a test plot in the 12 x 12 pot matrix to form the 100% vegetative cover condition. Soil was carefully placed around each pot, so only sunlit and shadowed plants and soil formed the target in the field-of-view (FOV). The potted marigolds were removed randomly from the FOV to produce the desired percent cover. The actual percent vegetative cover was calculated from the number of pots in the FOV. The voids in the soil surface, created by removing pots, were filled with soil as each pot was removed. Reflectance measurements of the dusty miller were made for several vegetative covers that were less than 40% cover. The desired vegetative cover was achieved by clustering the potted dusty miller plants in the center of the monochromator FOV.

Spectral reflectance measurements were made over the range 400 to 1100 nm, in 10 nm increments, using an EG&G model 550/555 Spectroradiometer system. Each spectrum required about 4 min to complete. The field-of-view of the monochromator was 15°. The spectroradiometer was interfaced with a Hewlett-Packard Model 9830 Calculator for automatic

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data recording and processing. The monochromator was centered above each test plot and viewed the plot vertically from a height of 583 cm. The reference standard was a 15 cm square magnesium carbonate block which was positioned normal to the sun. The monochromator measured this surface by viewing it vertically from a distance of about 50 cm. The reflectance of each vegetation-soil target was calculated as a percentage of the standard's reflectance. Measurements were made on clear days between 1030 and 1430 hr local standard time on 13, 14, 17, and 22 June 1980. An Eppley radiometer and a strip chart recorder were used to measure and record total solar illumination during the scanning period. The reflectance spectra were normalized to each other by using normalization coefficients that were calculated by dividing the maximum solar illumination measured for a spectral scan by the measured solar illumination for a scan.

RESULTS

Total solar illumination ranged from 1.3 to 1.6 langley during the recording periods. The least solar illumination occurred at the beginning of the measurement period, about 1030 to 1100 hr, and the maximum occurred between 1230 and 1300 hr local standard time. The vegetative cover was varied by randomly removing the potted plants from the FOV in the test plot. Evaluation of the soil and vegetation reflectance curves shows that these targets can be differentiated from each other. The reflectance contrasts between the targets were not equal in the visible and infrared regions.

Vegetation on Sand Soil

The sand soil (0% cover) had a higher reflectance in the 400 to 730 nm region than the marigold (100% cover), but had a lower reflectance in the 780 to 1100 nm region (Figure 1). In the 400 to 730 nm region, the reflectance differences between the bare soil and marigold (100% cover) ranged from 10% to 36%, but in the 780 to 1100 nm region the reflectance values differed less than 10%. The largest reflectance between the marigold cover and the bare soil was in the 680 to 720 nm region. Varying the marigold cover on the sand soil from 0% to 100% cover created different spectral reflectance curves for each vegetation-sand soil target.

In the 400 to 730 nm region, the target reflectance varied inversely with the percentage of vegetation, i.e. as the percent vegetation decreased the reflectance from the target increased. The reflectance curves for the marigold-sand soil targets with greater than 18% cover were more similar in shape and slope to that of the 100% vegetative cover target than they were to the reflectance curve of the sand soil (0% cover).

In the 780 to 1100 nm region, the reflectance varied directly with the percent vegetation. Targets with 75% to 100% cover differed less than 3% in their reflectance, whereas targets with less than 28% cover were only slightly more

reflective than the bare soil.

The relations between the percent vegetative cover and the percent reflectance for the 10 nm bandpasses centered at 450, 550, 700, and 850 nm were described using polynomial regression analysis (Figure 2). These curves show the inverse relations between the percent vegetative cover and the percent reflectance in the visible region. The better correlations between reflectance and percent cover were found at 550 and 700 nm, which had R^2 values of 0.85 and 0.94, respectively. In the IR region, the direct relation between reflectance and cover is described by the regression curve; although the slope of the curve indicates that large changes in cover are required before substantial reflectance differences can be measured.

These data show the introduction of any marigold cover to the sand soil will alter the soil's reflectance, but recording these changes is not equally determined in the visible and infrared regions. The influence of vegetation on the soil reflectance was noticeable in the visible region for covers greater than 8%, but significant change (at 95% level of confidence) in the sand reflectance was not found until vegetative cover was 21% cover. In the infrared region, covers greater than 95% were needed to significantly change the sand soil's reflectance.

The reflectance curves for the sand soil and the dusty miller targets were similar to that of the marigold-sand targets in that the greatest reflectance differences were found between 400 and 730 nm. These two targets had similar reflectance characteristics in the near IR region, 780 and 1100 nm. The reflectance differences ranged from 4% at 400 nm to 30% at 730 nm, but were 2% to 3% in the 780 to 1100 nm region.

The dusty miller cover on the sand soil was varied between 0% and 30% and the reflectance measured for each target (Figure 3). The curves for these targets show an inverse relation between the reflectance of the dusty miller-sand soil targets and the percent vegetative cover in the visible and IR regions. The reflectance curves for the target with 12% and 22% cover, although displaced, were similar to the reflectance curve of the bare soil. The reflectance curve for the target with 30% cover was more like that of the 100% dusty miller cover than the bare sand soil. Polynomial regression analysis of the percent reflectance at 450, 550, 700, and 850 nm and percent cover shows that moderate changes in cover are needed before small changes in the soil's reflectance can occur. The reflectance curves in Figure 4 show that the dusty miller vegetation can alter the sand reflectance at all cover values, but significant changes (at 95% confidence level) in the sand soil reflectance occurred in those targets with 34% cover.

Vegetation on Organic Loam Soil

The spectral reflectance curves for marigold and the bare organic loam soil (0% cover) are shown in Figure 5. These curves differed by less than 5% in the visible region, where the marigold was slightly more reflective than the

organic soil. The chlorophyll absorption band at 650 and 730 nm caused the marigold reflectance to be less than the organic soil. The reflectance differences between the marigold and organic soil in the 400 to 730 nm region were too small for positive differentiation between the two targets.

Varying the percent marigold cover on the organic soil substantially changed the reflectance characteristics of the soil, primarily in the near IR region. There was a direct relation between percent cover and percent reflectance from the marigold-organic loam soil targets. Polynomial regression analysis of the relation between percent cover and percent reflectance in the visible region, 450, 550, and 700 nm, shows a small variation in reflectance was associated with a large change in percent cover (Figure 6). The reflectance in the near IR region (850 nm) was directly related to the percent vegetative cover, $R^2=0.97$. The regression curve of this relation shows the ratio of percent reflectance to percent cover was about 2:5.

Statistical analysis of the reflectance differences revealed a significant difference (at 95% level of confidence) between the soil and those targets of $\geq 12\%$ cover.

The reflectance curves for the dusty miller (100% cover) and the dark-toned organic loam soil (0% cover) show the dusty miller had 10% to 15% greater reflectance than the organic loam soil in the 400 to 730 nm region, and about 40% greater reflectance in the 780 to 1100 nm region. Increasing the vegetative cover on the organic loam soil increased the reflectance at all wavelengths (400 to 1100 nm).

The reflectance curves of the dusty miller and the organic loam soil targets with 5%, 16%, and 35% cover are shown in Figure 7. These curves differed by only 3% to 4% in the 400 to 730 nm region, but by 10% to 15% in the 800 to 1100 nm region.

Regression analysis of the percent reflectance and percent cover shows a direct relation between them (Figure 8). The regression curve shows that large changes in cover resulted in only small increases in target reflectance in the 400 to 730 nm region. In the 780 to 1100 nm region, the ratio of reflectance to cover was about 3:10.

The reflectance curves in Figure 7 show that a 5% cover was enough to substantially modify the reflectance of the organic loam soil. Statistical evaluation of the vegetative cover on the organic loam soil revealed that 11% cover had a significant effect (at 95% level of confidence) on the soil reflectance.

DISCUSSION

The reflectance characteristics of the sand and organic loam soil were affected by the addition of all vegetation to the soils. The vegetative effects were related to the vegetation color, percent cover, and the spectral region. Changes in the soil reflectance were greatest in those

spectral regions where large reflectance contrasts were found between the vegetation and the soil. For example, both the green-colored marigold and the gray-colored dusty miller readily altered the sand soil reflectance in the visible region, as well as the organic soil's reflectance in the near IR region. When the vegetation and the soil had small reflectance contrasts, large changes in percent cover were needed to produce even slight changes in reflectance. This was apparent for the marigold on the organic soil in the 450 to 730 nm region and for the dusty miller on the sand soil in the 780 to 1100 nm region.

The reflectance contrasts between vegetation and soil are important for the monitoring of vegetative cover or evaluating crop vigor, because differentiation between crop and soil would be impossible or, at least, severely limited when reflectance contrasts were low. The low contrast between soil and vegetation could explain why some desert and semi-desert plants are not readily detectable and other species are easily detected, even on small-scale photography. Vegetation did not uniformly change the soil's reflectance characteristics throughout the 400-1100 nm spectrum, nor were these effects the same for the light- and dark-toned soils. In the 400 to 730 nm region, an inverse relation was found between the percent reflectance from the sand-vegetation targets and the percent cover, either marigold or dusty miller. In this same spectral region, direct relations were found between the reflectance from the organic loam soil-dusty miller targets, but not for the marigold-organic loam soil target, for reasons previously discussed. In the IR region, the target reflectance was directly related to the percent green marigold cover on both the sand and the organic loam soil. In the IR region, reflectance from the sand-dusty miller targets were not related to the dusty miller cover because of the low reflectance contrast between the sand and dusty miller. These results were similar to those reported by Colwell (1974) and Holben (1980) for green vegetation on a light-toned soil.

The results of this study can be applied to the interpretation of different types of imagery for evaluating vegetative cover. When using panchromatic photography the association is often made that gray tone levels are directly proportional to the percent vegetative cover in the scene. The data presented here show that this can be a reasonable approximation for uniform, light-toned soil conditions. For uniform, dark-toned soil, however, the photo tone would depend on the vegetative color, because both direct and inverse photo tone-vegetative cover relations can be made. On color infrared photography, direct or inverse photo tone/color-vegetative cover relations are also possible, depending on the soil and vegetation reflectance characteristics in the green IR spectrum. The intensity of the red on the IR photography could be related to the percent vegetative cover, but reflectance from a gray-colored vegetation could be similar to that of the soil, which would make their differentiation difficult on color IR photography. Differentiation of the dusty miller and the sand soil would be difficult in the IR region because of their similar IR reflectance.

Ratioing reflectance in the visible and IR regions has been used for monitoring vegetative cover. Pearson (1976) and Holben (1980) found the ratio of IR (775-825 nm)/visible (650-700 nm) was highly correlated with the vegetative cover. The reflectance measurements made here show similar correlation between vegetative cover and target reflectance in the visible (550-700 nm) and IR (850 nm) region (Figures 2 and 4). The IR visible ratio for the green vegetation on dark-toned soils could be reduced to a correlation between percent cover and IR reflectance because of the close similarity between the marigold and organic soil in the visible region (Figures 6 and 8).

The results of this study, as well as those of Tucker (1979), show that cover can be estimated from target reflectance. However, the use of leaf area index (LAI) as a measure of vegetative cover may not be an accurate measure of cover. LAI, as a measure of the total leaf area per unit of ground area, is affected by leaf phyllotaxy and the canopy closure. Leaf phyllotaxy has been shown to effect vegetative reflectance in both the visible and IR regions, if a sufficient number of the leaf layers are in the FOV. Maximum reflectance in the visible range was achieved in the laboratory by two stacked leaves, and in the IR region by 6 to 8 stacked leaves (Meyers, et al, 1966). Field studies have generally confirmed these numbers, in that the maximum IR reflectance from a vegetative surface is achieved at an LAI of about 6 to 10. Using LAI as a measure of cover in reflectance studies must assume either a uniform, closed canopy with little or no soil in the FOV, or 100% canopy closure at some LAI. The effects of cover on soil reflectance described here suggest LAI can be misleading approximation of cover, particularly when canopy closure is not obtained. Targets of widely spaced individuals with LAI >1 could have percentages of soil and shadow in the FOV that would significantly affect the target's reflectance. The effects described here of vegetative cover on soil reflectance and the correlation of LAI and reflectance reported by others indicate more study of the LAI-canopy closure-reflectance relations is needed, particularly for discontinuous canopies.

Statistical analysis of the reflectance data revealed that the percent cover having significant effect on the soil's reflectance varied by spectral region, soil type, and vegetation. This is predictable considering the differences between vegetation and soil reflectance. In the 450 to 1000 nm region the sand soil reflectance characteristics were significantly altered by 25% marigold or 34% dusty miller cover, whereas the organic soil reflectance was significantly changed by 12% and 11% cover. When large reflectance contrast existed between soil and vegetation, only small vegetative covers were needed to alter the soil's reflectance. This relation is shown by the various regression curves. Because the vegetative effects were not uniform throughout the 400 to 1100 nm region, the percent cover significantly changing the soil reflectance would change in accordance with the reflectance contrast between the soil and vegetation conditions. In the visible region, 450-650 nm, the green marigold covers of 19% and 50% significantly

changed the reflectance characteristics of the sand and organic soil targets, respectively. The dusty miller, which had a lesser reflectance contrast with the sand soil than the marigold, needed a greater percent cover, 26%, to significantly change the sand reflectance, whereas only 18% cover was needed for the organic loam soil. In the near IR region (800-1000 nm) the small reflectance contrast between the sand and the vegetation necessitated a large cover before a significant change in reflectance was found. A 95% cover was needed for marigold cover, while no statistical difference was found between the dusty miller and the sand soil reflectance in this region. The organic loam soil and vegetation had large reflectance contrasts in the near IR, and only 6-7% cover was needed to alter the soil's reflectance. The interactions of the soil and vegetation reflectances measured in this study show the necessity for considering both soil and vegetation and their reflectance characteristics as part of the image analysis procedure.

CONCLUSIONS

Vegetation on a soil surface altered the soil's spectral reflectance in a predictable manner. The reflectance curves of the soil-vegetation targets were intermediate and proportional to the reflectance curves of the soil (0% cover) and the vegetation (100% cover).

All additions of vegetation to the sand or organic loam soil altered the soil's reflectance characteristics, but these effects varied with vegetation type and spectral region. Reflectance varied inversely with the percent cover in the visible region and varied directly with percent cover in the IR region. Reflectance from the organic loam soil was little affected by marigold cover in the visible, but had a direct relation with dusty miller cover. In the near IR region the organic soil reflectance was strongly and directly related with both the marigold and dusty miller covers.

The percent vegetative cover significantly altering the soil's reflectance varied with vegetation, soil type, and spectral region. For the sand soil, 19% marigold and 26% dusty miller changed the reflectance in the visible; and 95% marigold in the near IR. Dusty miller cover did not change the sand reflectance characteristics in the IR region. The percent vegetative cover changing the reflectance of the organic soil was 50% marigold and 18% dusty miller in the visible, and 6% marigold and 7% dusty miller in the near IR.

Spectral regions permitting the differentiation between the soil and vegetation targets were different for each soil and vegetation condition. For the sand soil targets the visible region was better than the infrared region. In the infrared region the green marigold could be differentiated from the sand soil, but the gray-toned dusty miller was not easily discriminated. For the organic loam soil the infrared region permitted a better separation of soil and vegetation than did the visible region.

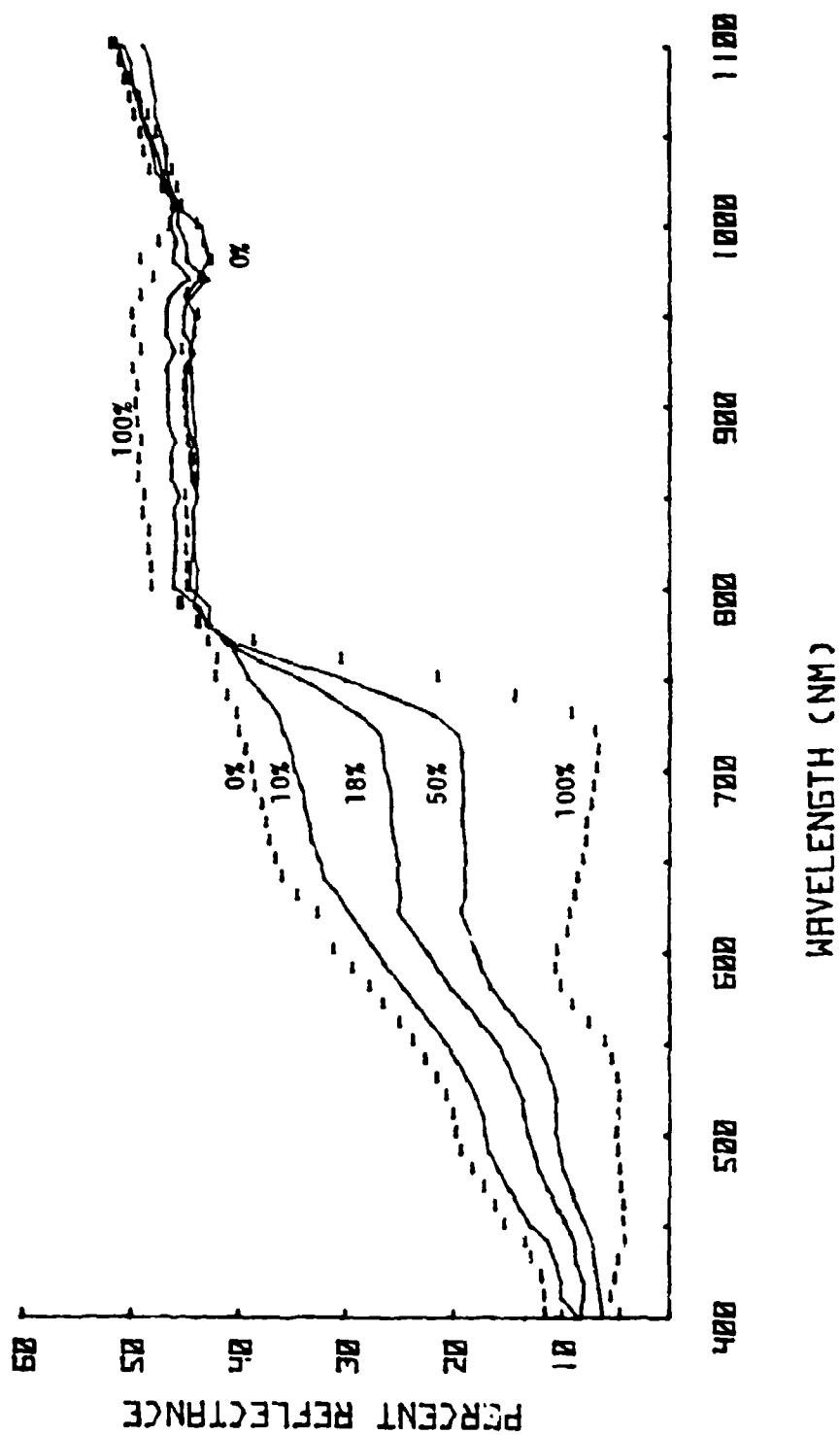


Figure 1. Reflectance Curves for Sand-Marigold Targets with Different Vegetative Covers.

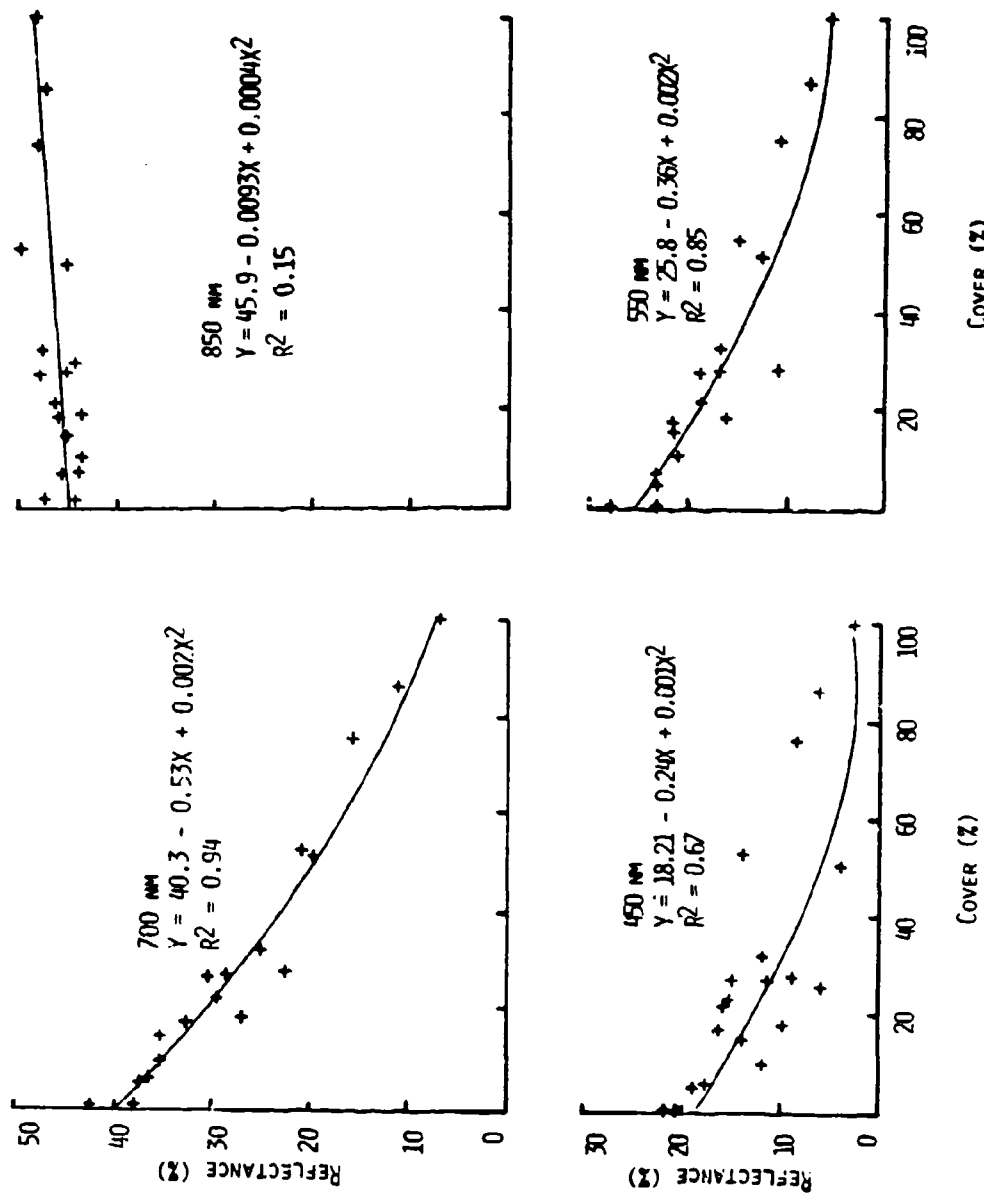


Figure 2. Regression Curves for Reflectance at 450, 550, 700 and 850 nm and Percent Cover of Sand-Marigold Targets.

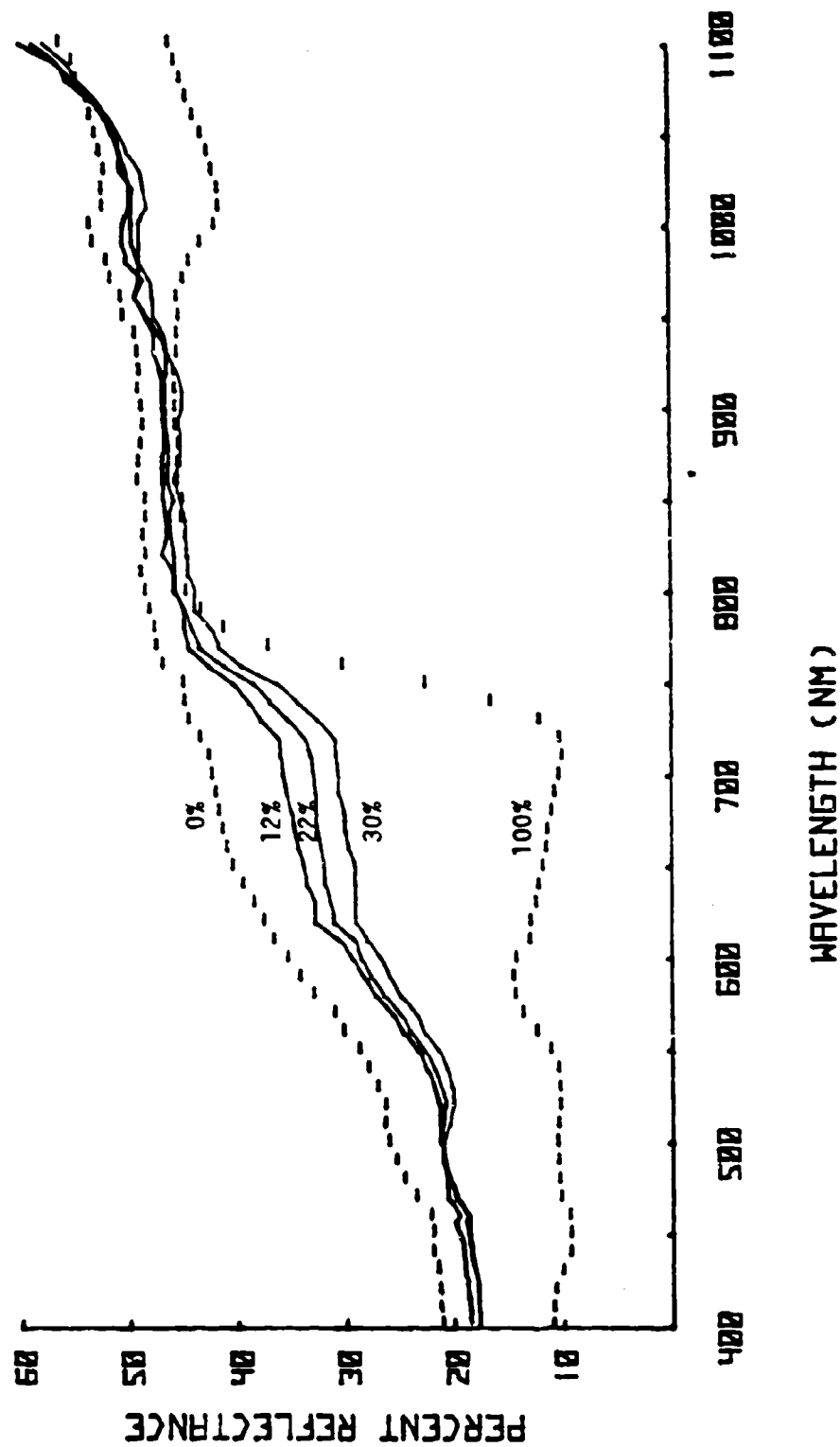


Figure 3. Reflectance Curves for Sand-Dusty Miller Targets with Different Vegetative Covers.

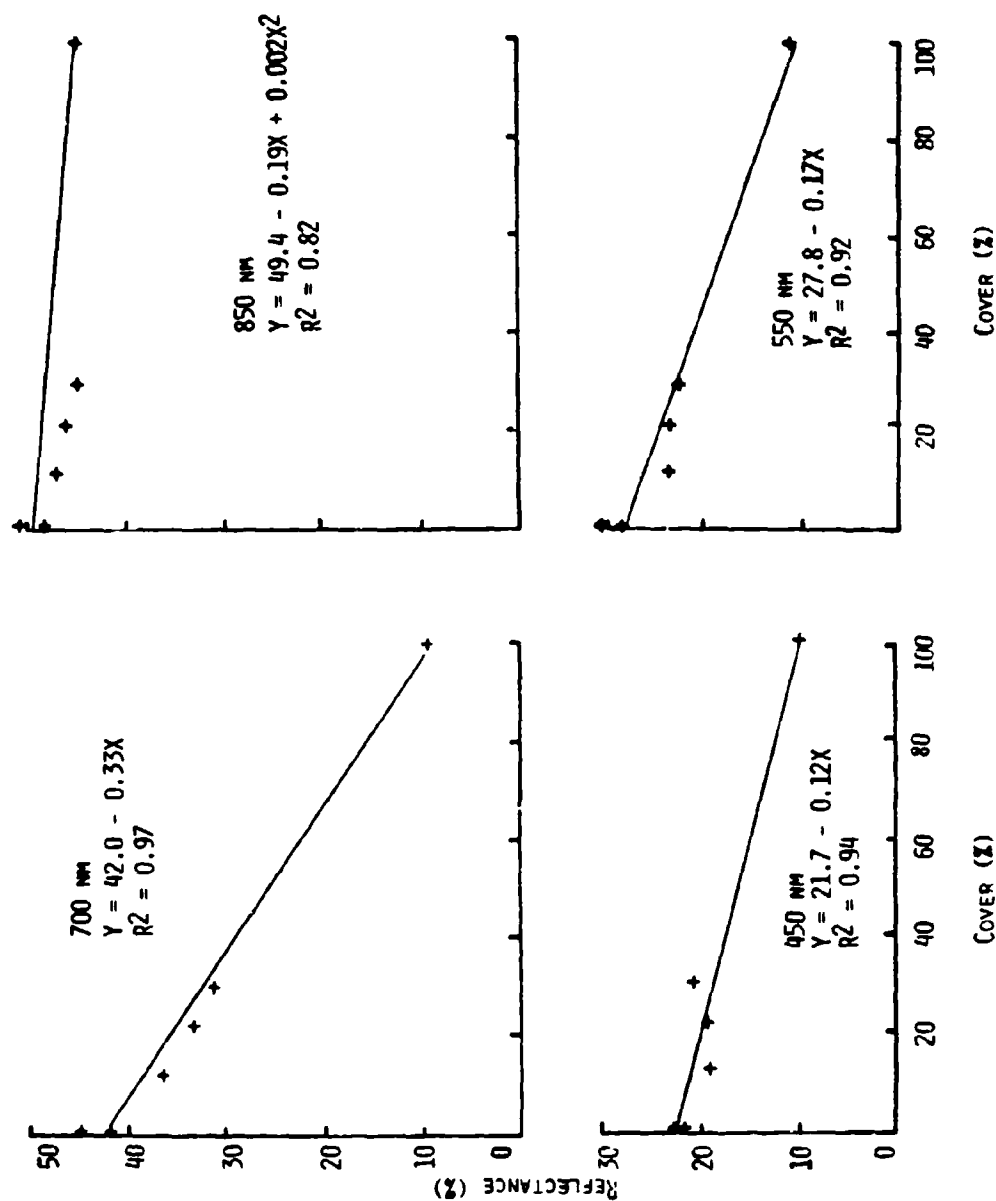


Figure 4. Regression Curves for Reflectance at 450, 550, 700 and 850 nm and Percent Cover of Sand-Dusty Miller targets.

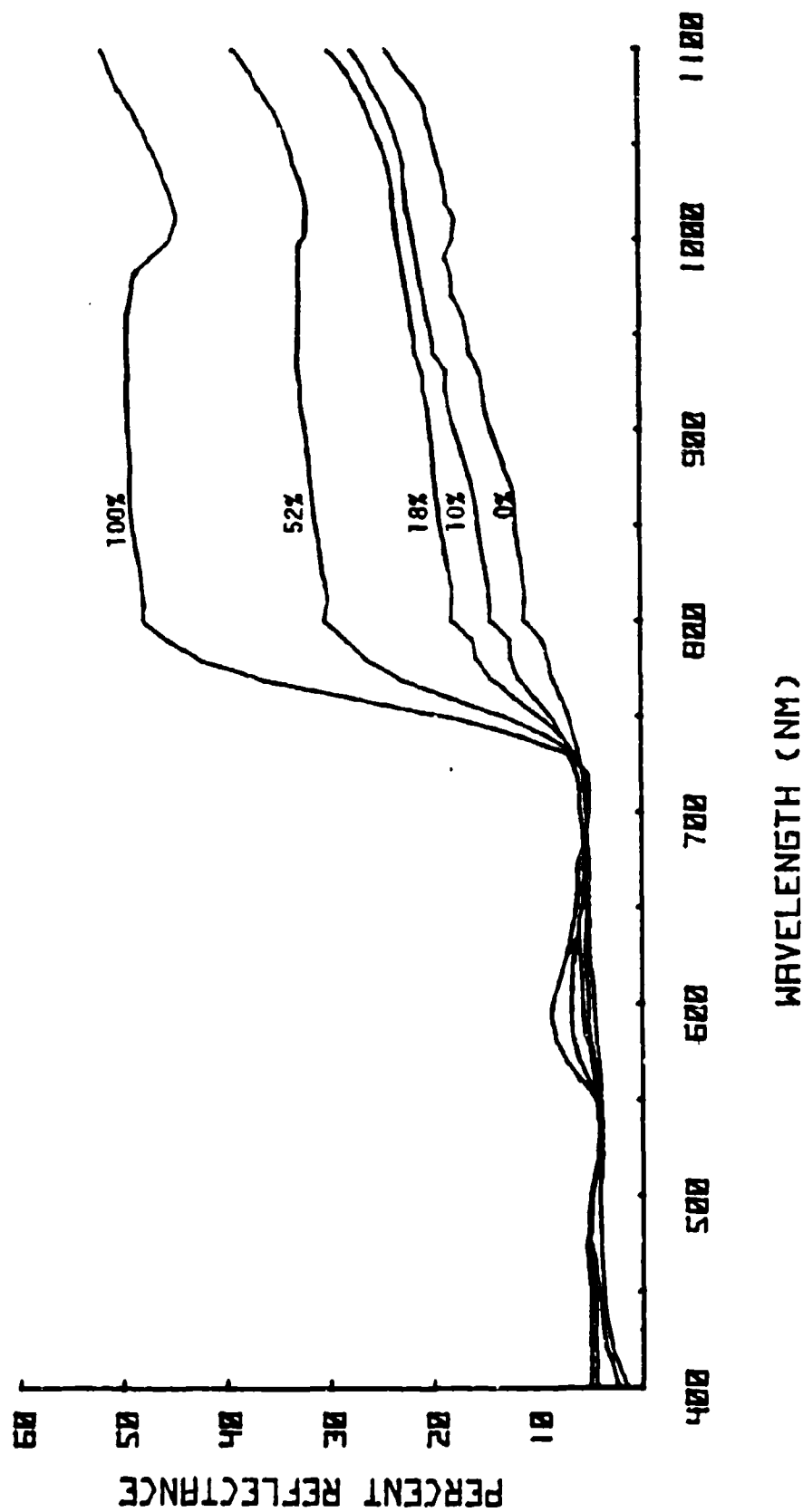


Figure 5. Reflectance Curves for Organic Loam Soil-Marigold Targets with Different Vegetative Covers.

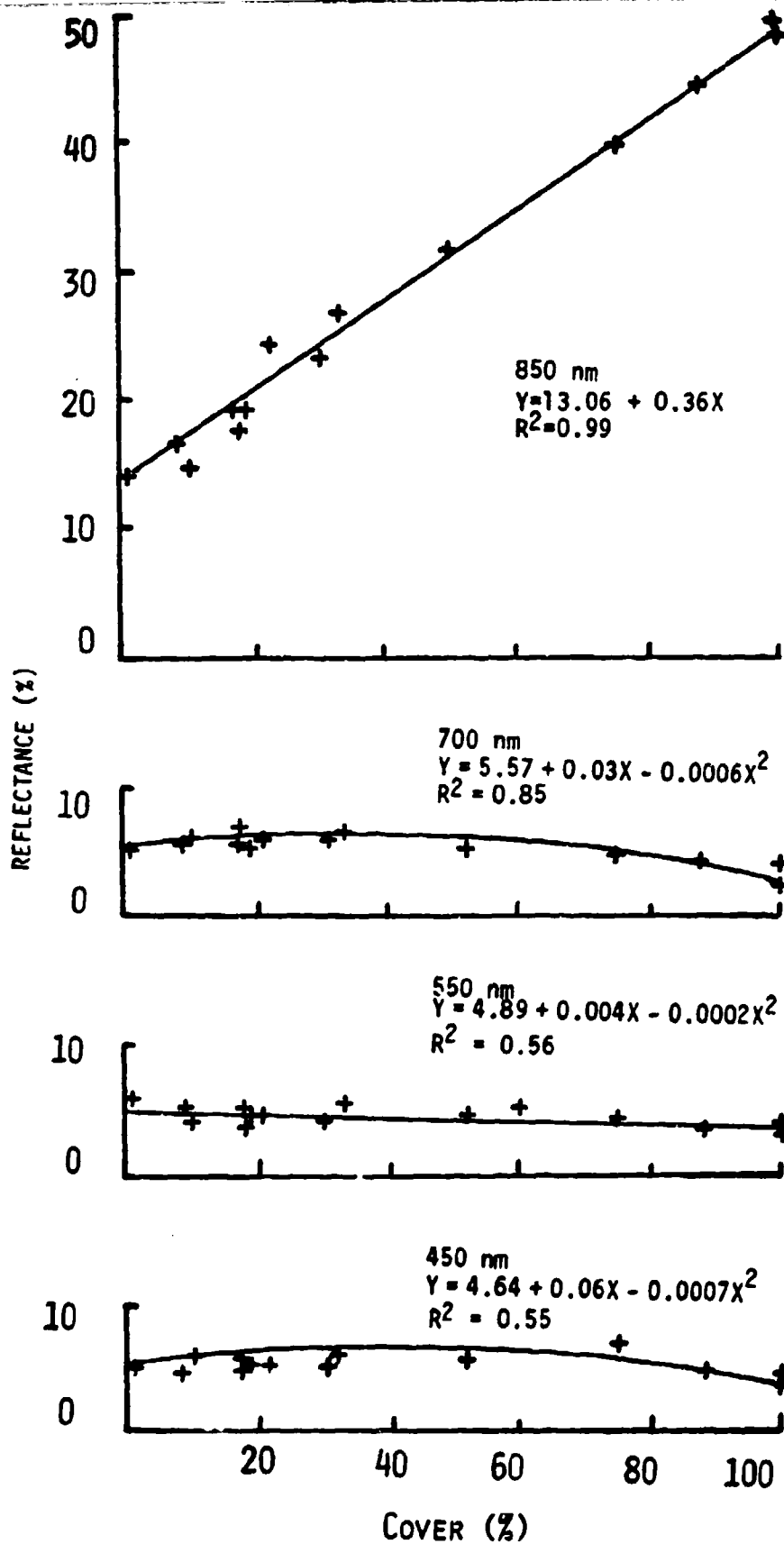


Figure 6. Regression Curves for Reflectance at 450, 550, 700 and 850 nm and Percent Cover of Organic Loam-Marigold Targets.

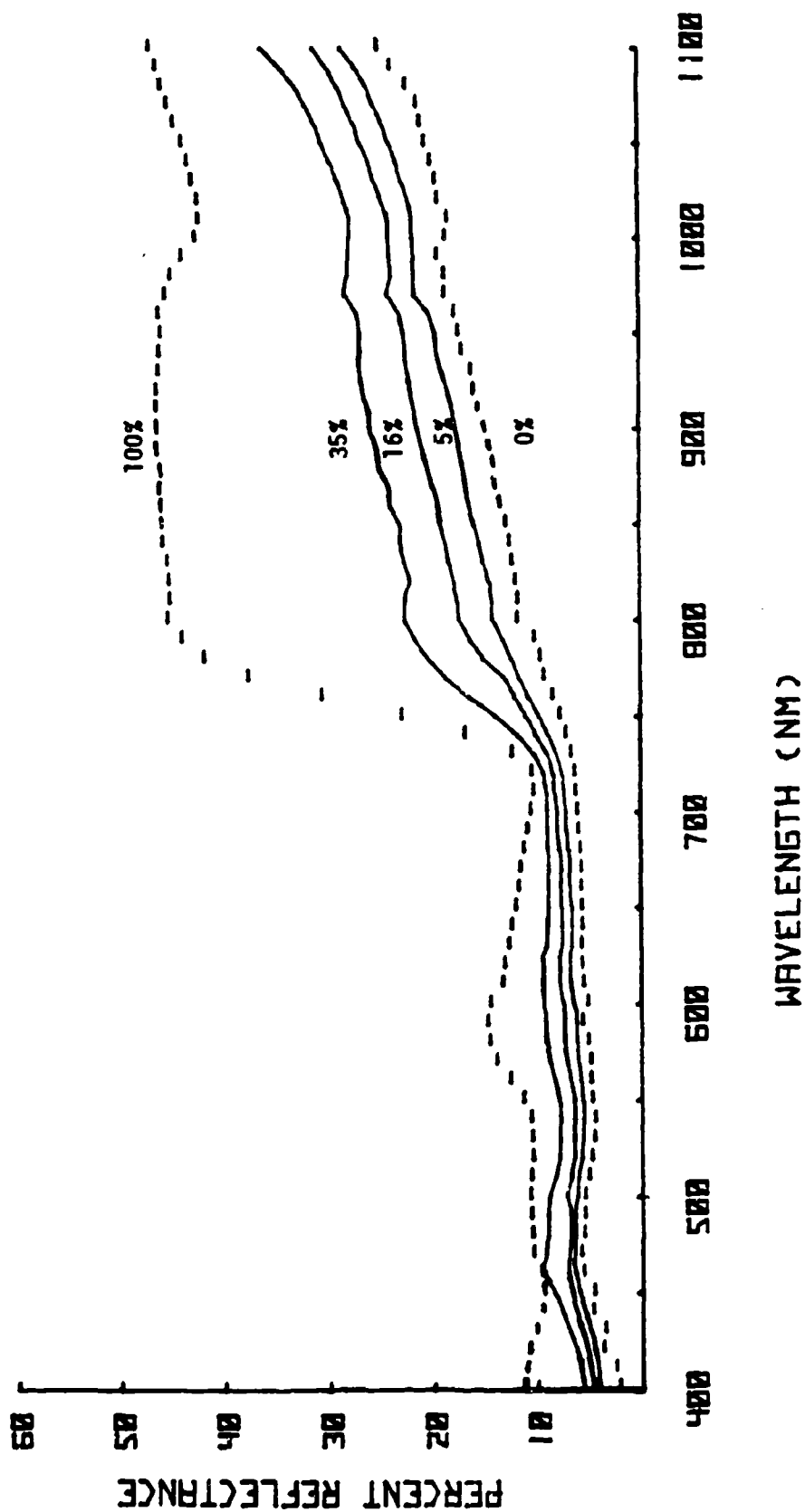


Figure 7. Reflectance Curves for Organic Loam Soil-Dusty Miller Targets with Different Vegetative Covers.

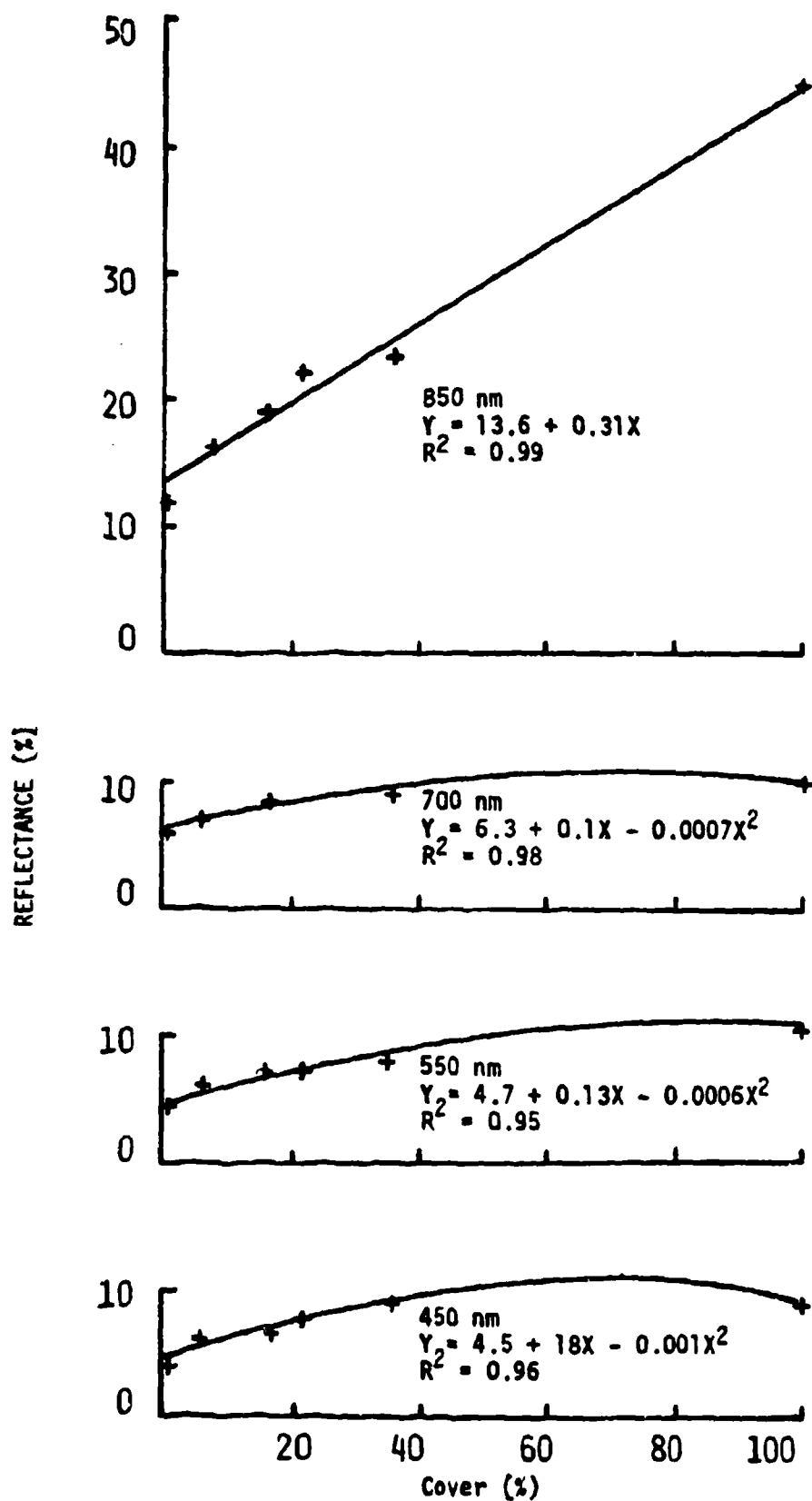


Figure 8. Regression Curves for Reflectance at 450, 550, 700 and 850 nm and Percent Cover of Organic Loam-Dusty Miller Targets.

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